Mars Sample Return (MSR) Sample Receiving Facility (SRF) Assessment Study

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NASA Johnson Space Center

National Academy of Sciences – Space Science Week

Committee on Astrobiology and Planetary Science (CAPS)

Committee on Planetary Protection (CoPP)

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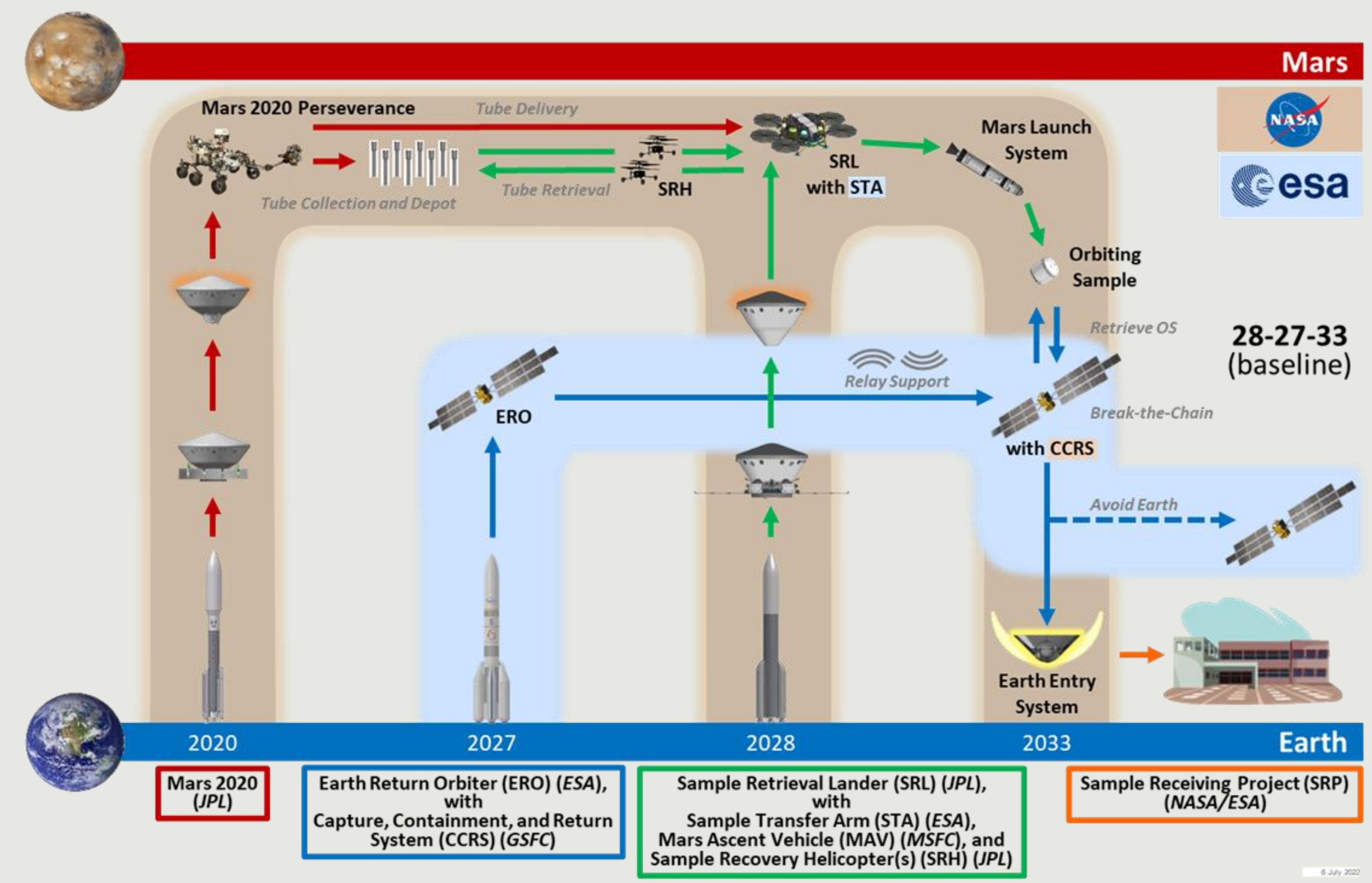
Astromaterials Research and Exploration Science
Johnson Space Center

INTRODUCTION

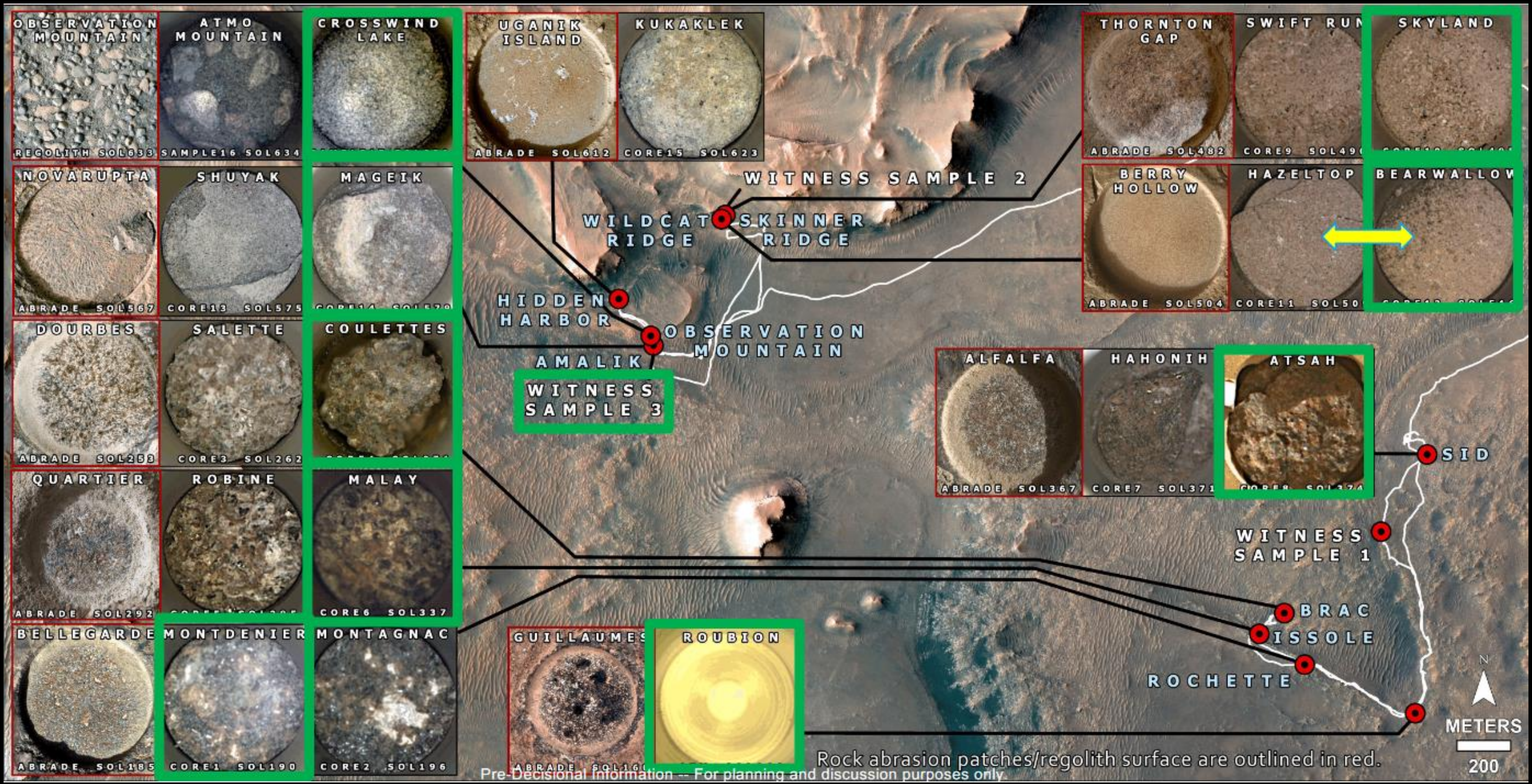
- Mars Sample Return (MSR) is a joint venture between NASA and ESA.

- The Campaign will notionally return between 10-26 geologically diverse samples (plus witness tubes) able to answer an array of science objectives.

- One of the high priority science objectives is to "assess and interpret the potential biological history of Jezero Crater, including assessing returned samples for the evidence of life." (iMOST Report)



Introduction



First samples from Delta Front Campaign

Green highlights tubes cached at Three Forks

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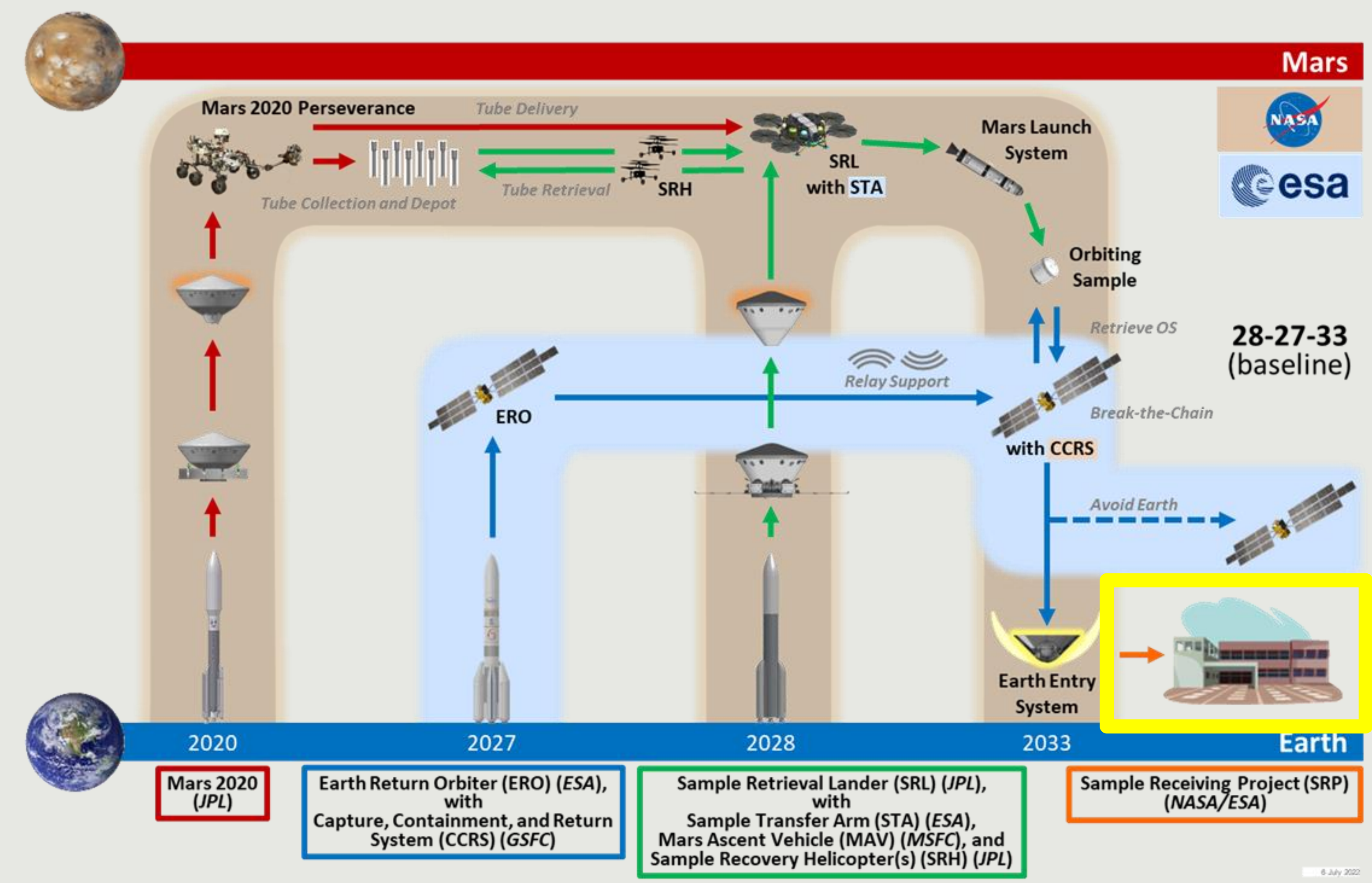


Sample Receiving Project

Mars Sample Return Program

1

Mars 2020 Sample Caching

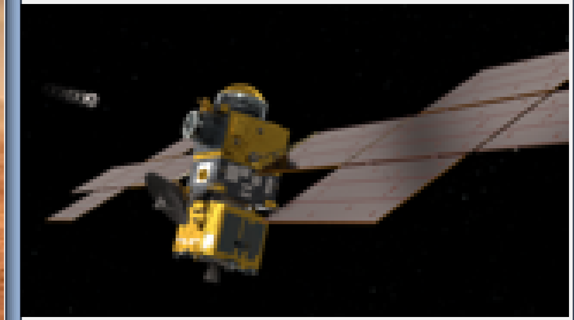
- *Collect samples of rock, regolith, and atmosphere*
- *Cache samples on the surface for retrieval*

2

Sample Retrieval Lander (SRL)

- *Retrieve samples cached by Mars 2020 rover*
- *Launch samples into orbit around Mars*

3



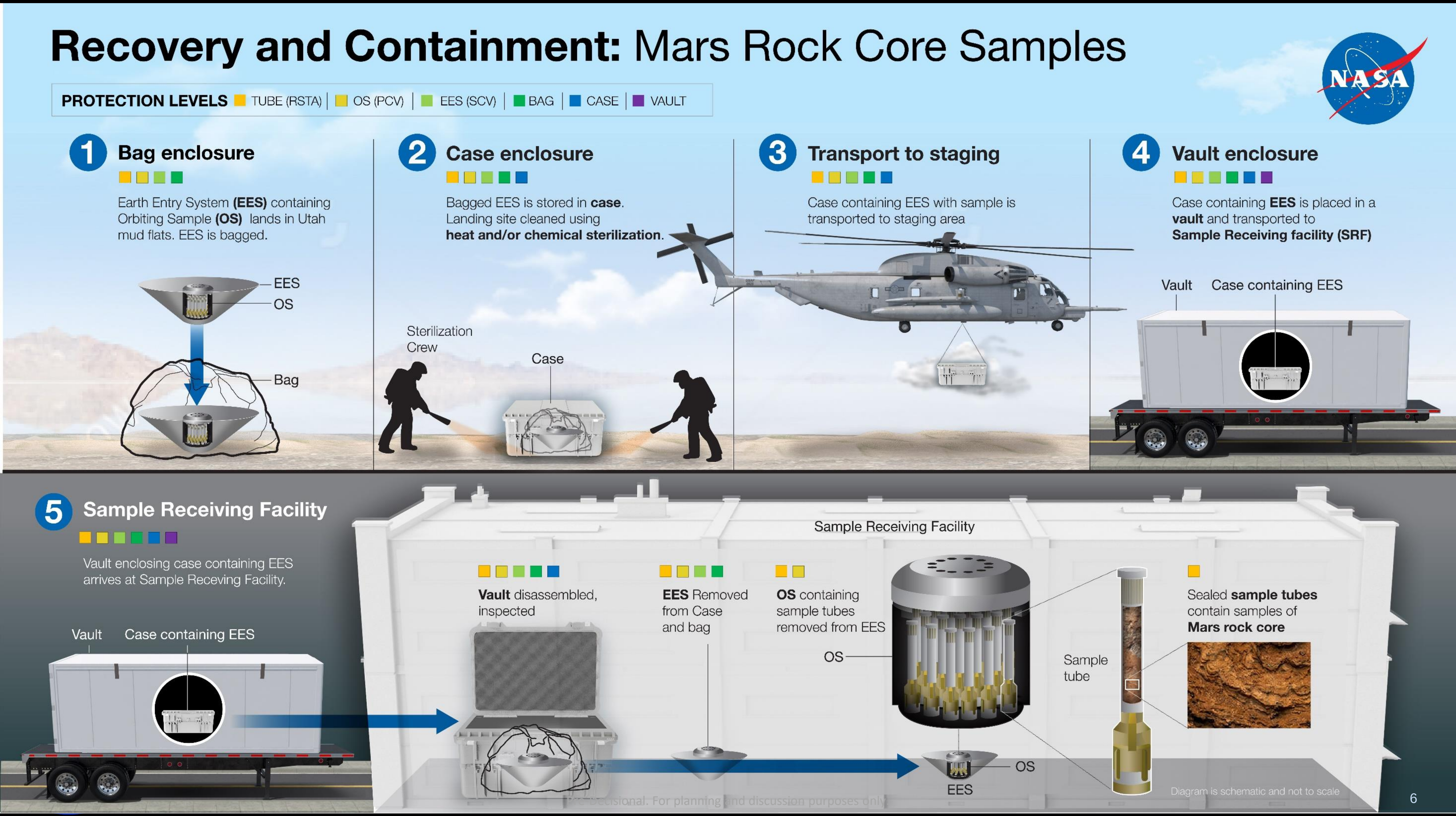
Earth Return Orbiter (ERO)

- *Capture and contain samples in Mars orbit*
- *Safely return samples to Earth for recovery at landing site*

4

Sample Receiving Project (SRP)

- *Recover and transport contained samples to receiving facility*
- *Safety assessment and sample containment*
- *Initial sample science and curation*



Recovery and Containment: Mars Rock Core Samples
NASA
PROTECTION LEVELS TUBE (RSTA) | OS (PCV) | EES (SCV) | BAG | CASE | VAULT
1 Bag enclosure
Earth Entry System (EES) containing Orbiting Sample (OS) lands in Utah mud flats. EES is bagged.
EES
OS
Bag
2 Case enclosure
Bagged EES is stored in case. Landing site cleaned using heat and/or chemical sterilization.
Sterilization Crew
Case
3 Transport to staging
Case containing EES with sample is transported to staging area
4 Vault enclosure
Case containing EES is placed in a vault and transported to Sample Receiving facility (SRF)
Vault
Case containing EES
5 Sample Receiving Facility
Vault enclosing case containing EES arrives at Sample Receving Facility.
Vault
Case containing EES
Sample Receiving Facility
Vault disassembled, inspected
EES Removed from Case and bag
OS containing sample tubes removed from EES
OS
Sample tube
Sealed sample tubes contain samples of Mars rock core
OS
EES
Diagram is schematic and not to scale
Pre-decisional. For planning and discussion purposes only.

Sample Receiving Project

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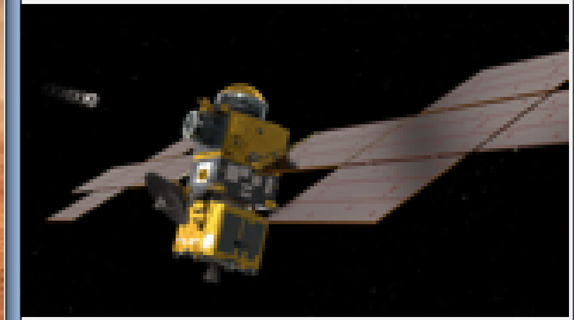

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MSR SRF Capabilities and Priorities

Receive Spacecraft

Hardware Disassembly

Sample Tube
Pre-Basic Characterization

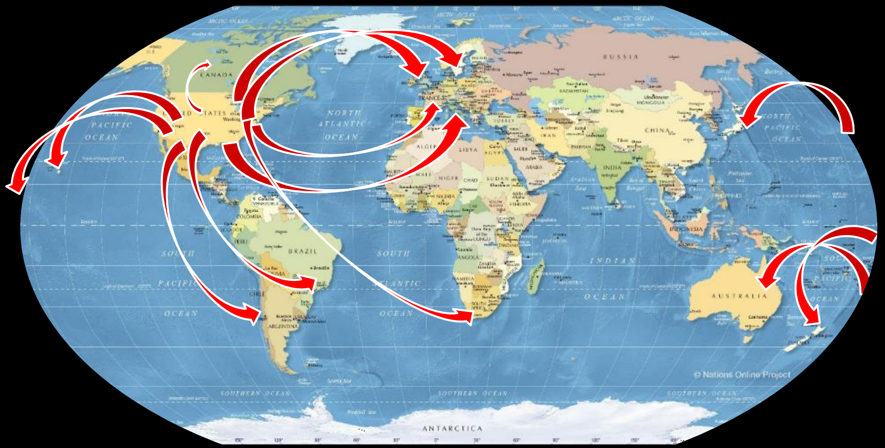
Samples Opened and
Basic Characterization

Samples Picked
and/or subdivided

Allocated Sample
Sterilization Process
(Irradiation or Heat)

Provide High-Containment & Contamination Control
Accommodate highest priority instrumentation
Fully operational by sample arrival
Enable rapid of release of samples

Sample Safety Assessment,
Preliminary Examination,
and/or Select Early Science



Global Safe Sample Distribution for
Earth-based Science Investigations

Foundational Information

- Planetary Protection Guidelines
  - Mars Sample Return (MSR) as a Planetary Protection Category V, Restricted Earth return due to the scientific opinion that Mars is of significant interest to the process of chemical evolution and/or the origin of life.
  - "Adopt appropriate measures" to "avoid [...] harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter." [Article IX of the UN Outer Space Treaty]

- Implementation Strategies for meeting Planetary Protection Guidelines
  - Mars Sample Receiving Facility (SRF) must provide high-containment (Biosafety Level (BSL)-4 equivalent).
  - Samples should be deemed abiotic and/or safe via the execution of a Sample Safety Assessment before they can be released from the SRF without sterilization.

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HIGH-CONTAINMENT FACILITY IMPLEMENTATION STRATEGIES

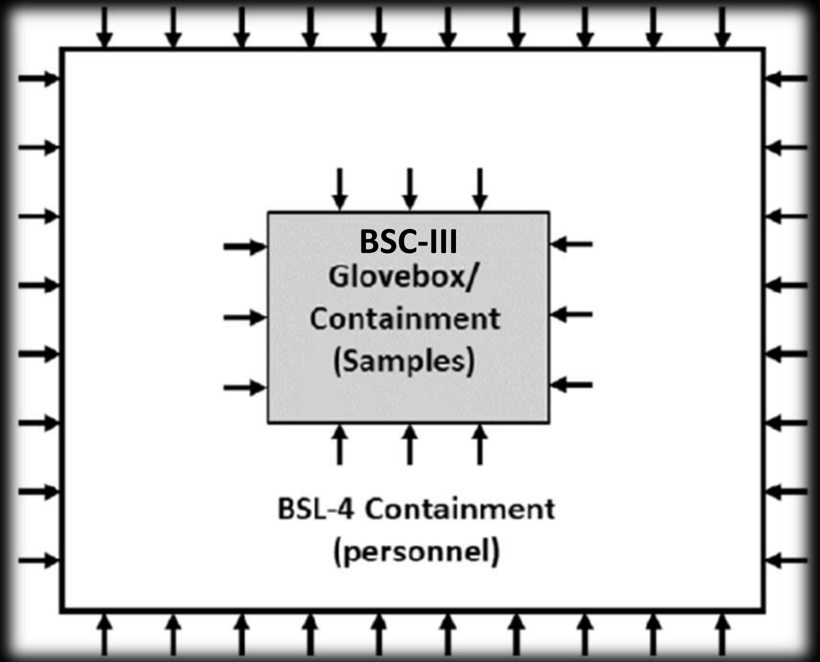
Personnel in Pressure Suits

Shope (USA)

Biosafety Cabinet (BSC)-III Cabinet Line

Porton Down (UK)

Traditional high-containment facilities are designed to protect scientists and the community from exposure to known hazard(s).



Negative Pressure Environment(s)

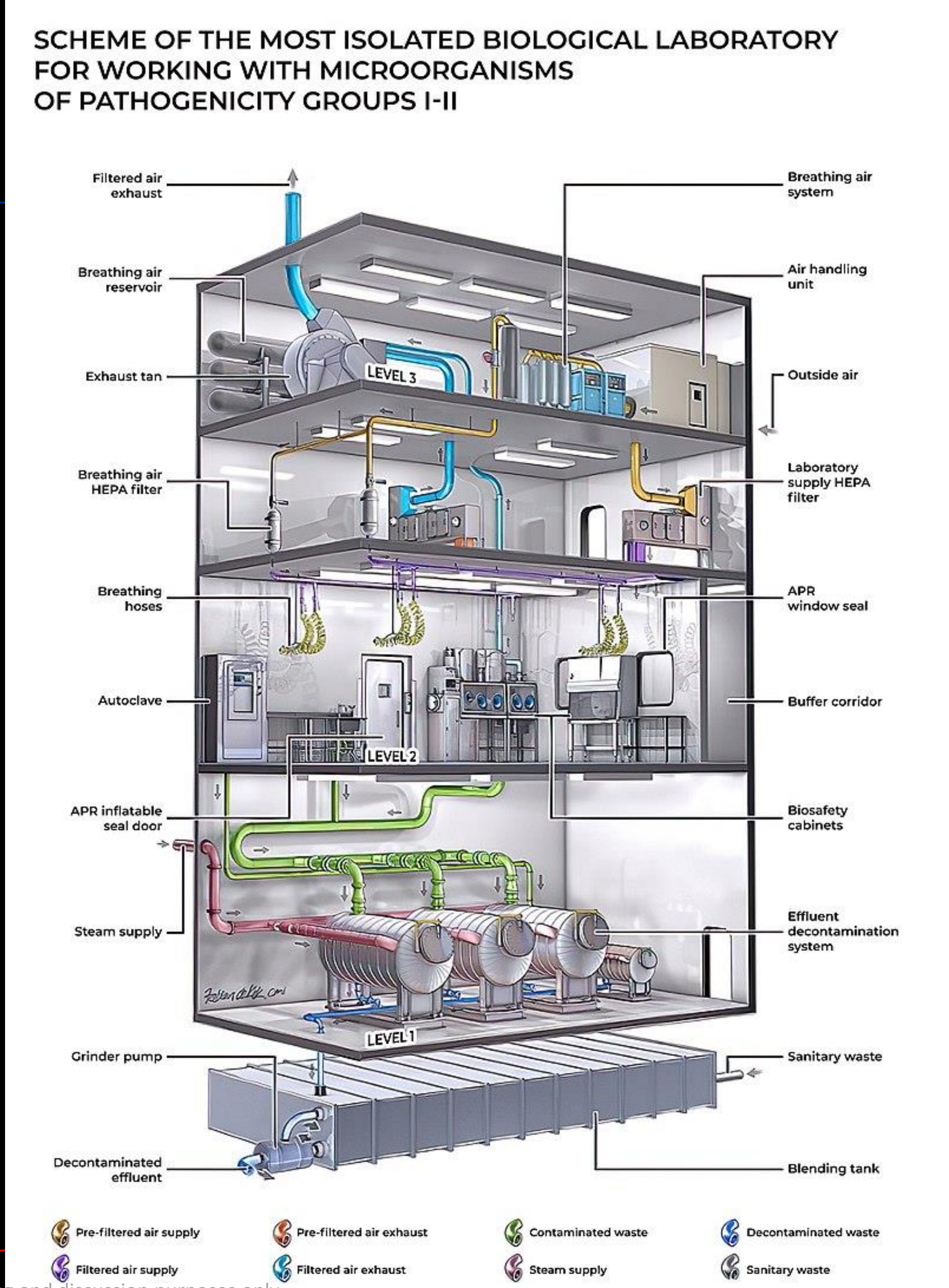
High-Containment Facility

Personnel in Pressure Suits

Shope (USA)

Biosafety Cabinet (BSC)-III Cabinet Line

Porton Down (UK)



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The Sample Safety Assessment Framework

- Framework to “evaluate only whether the presence of Martian life can be excluded in samples returned from Mars.”
  - Considers only carbon-based life
- It is a Framework – detailed Protocol still tbd

Bayesian Statistics
- Set criteria (e.g., $1\text{x}10^{-6}$)
- Set starting hypothesis (including use of Mars 2020 *in-situ* data)
- Estimate number of tests (depending on capture rate, sensitivity, specificity)

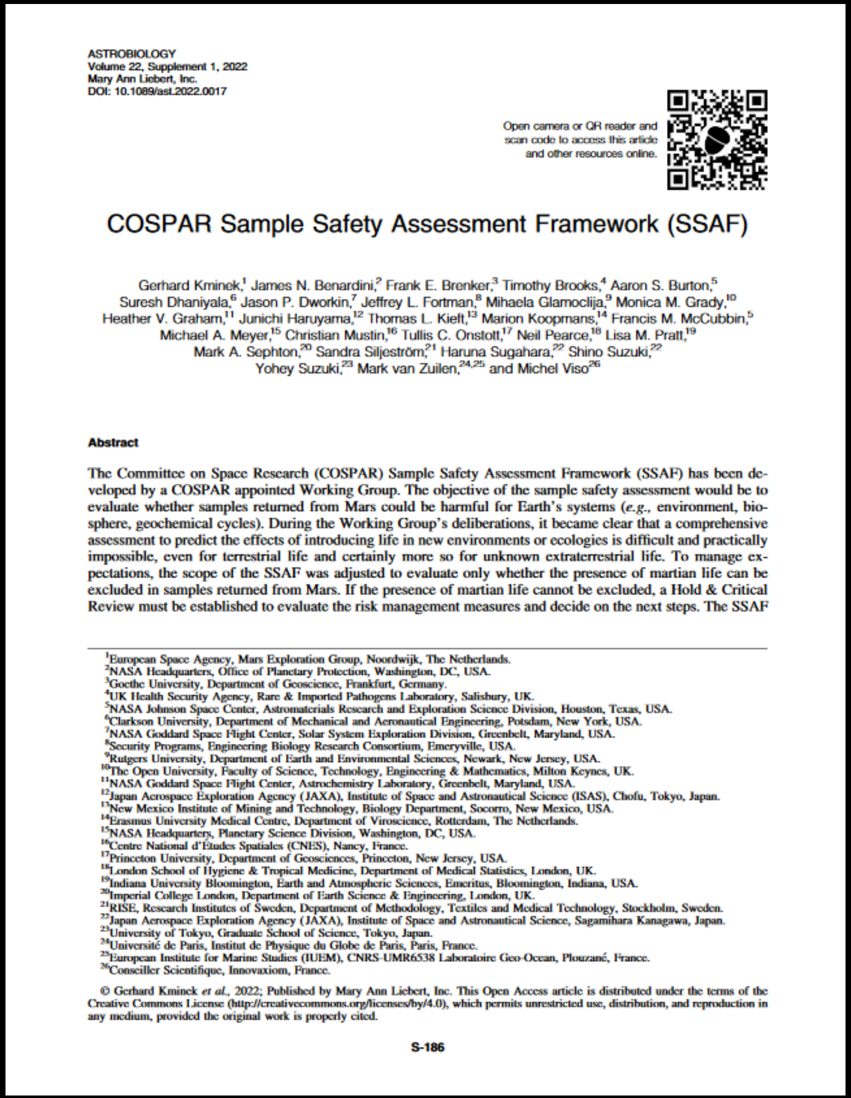
Subsampling Strategy
- Targeted subsampling (except for dust and certain clays)
- Requires structural, chemical, and mineralogical information covered in Steps 1 & 3 of the test-sequence

Decision Framework
- Quality control
- Data reduction process
- Criteria for test-sequence steps
- Pause and review in case of positive or uncertain detection

Test-Sequence
- Exclude presence of martian life
- Sensitivity & specificity of the overall test-sequence influences number of tests needed to achieve a certain level of assurance

After n-subsamples

Result
- Within pre-defined level of assurance
- Valid for one sample tube
- Informs pre-test probability for other samples tubes



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COSPAR Sample Safety Assessment Framework (SSAF)

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Abstract

The Committee on Space Research (COSPAR) Sample Safety Assessment Framework (SSAF) has been developed by a COSPAR appointed Working Group. The objective of the sample safety assessment would be to evaluate whether samples returned from Mars could be harmful for Earth’s systems (*e.g.*, environment, biosphere, geochemical cycles). During the Working Group’s deliberations, it became clear that a comprehensive assessment to predict the effects of introducing life in new environments or ecologies is difficult and practically impossible, even for terrestrial life and certainly more so for unknown extraterrestrial life. To manage expectations, the scope of the SSAF was adjusted to evaluate only whether the presence of martian life can be excluded in samples returned from Mars. If the presence of martian life cannot be excluded, a Hold & Critical Review must be established to evaluate the risk management measures and decide on the next steps. The SSAF

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S-186

Pristine Facility Implementation Strategies

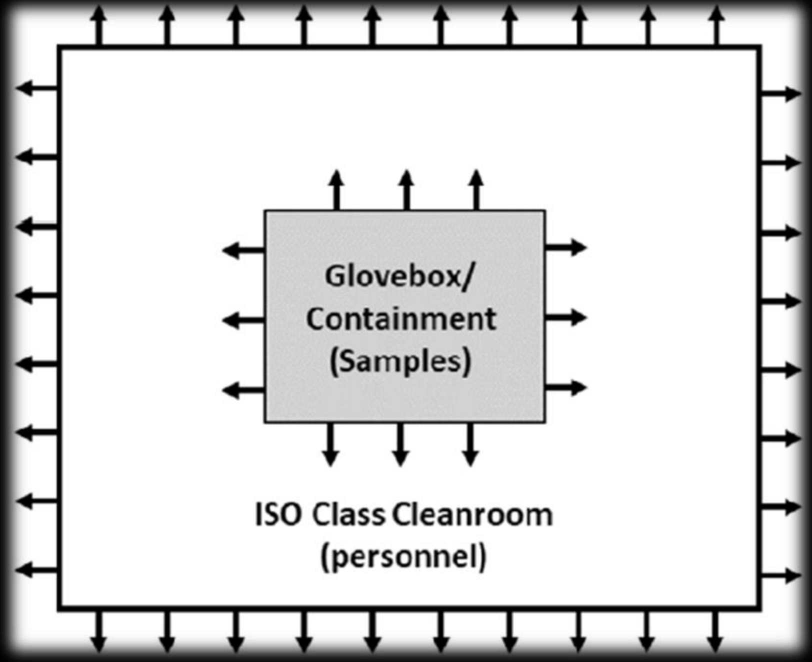
Cleanroom in Full Bunny Suits

Cosmic Dust Laboratory JSC

Gloveboxes

Apollo Laboratory JSC

Properly handling, examining, and curating Martian samples also requires that the samples be protected from terrestrial contamination so Planetary Protection (PP) and Science investigations are not impeded.



Positive Pressure Environment(s)

Pristine Facility Implementation Strategies

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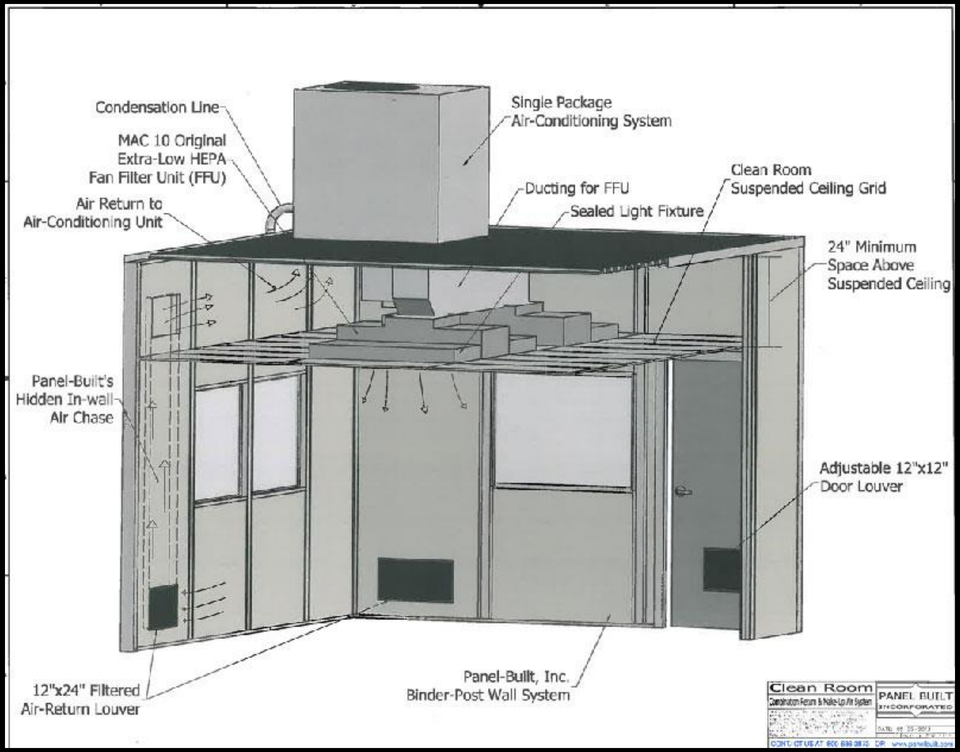
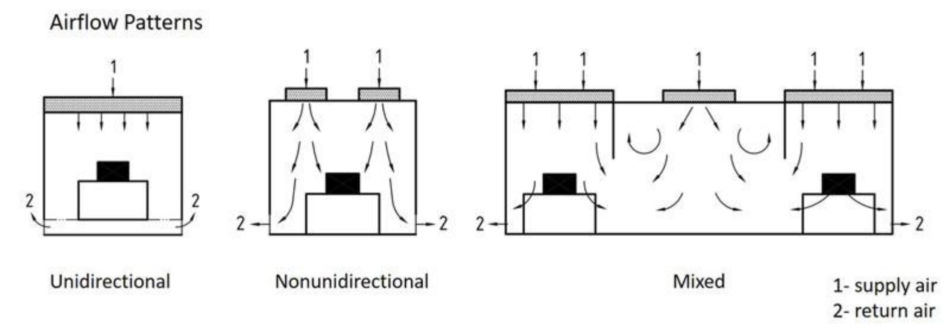
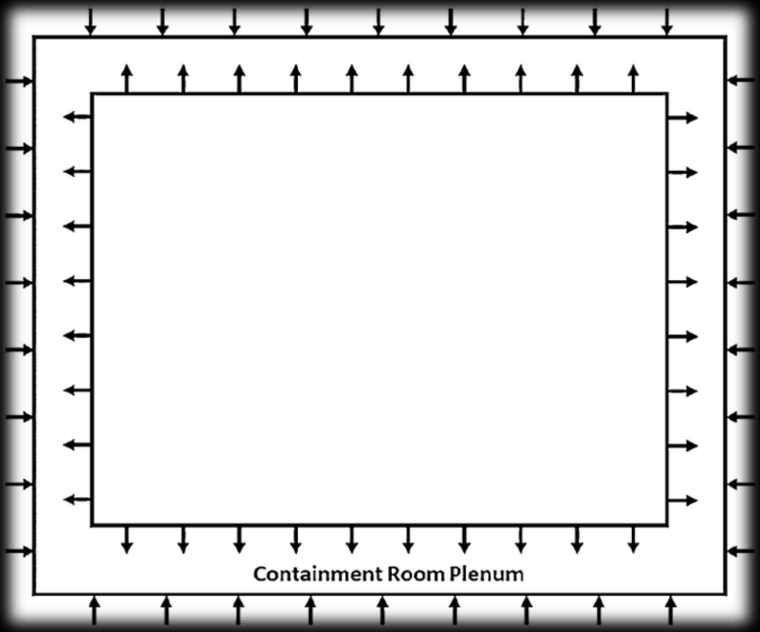




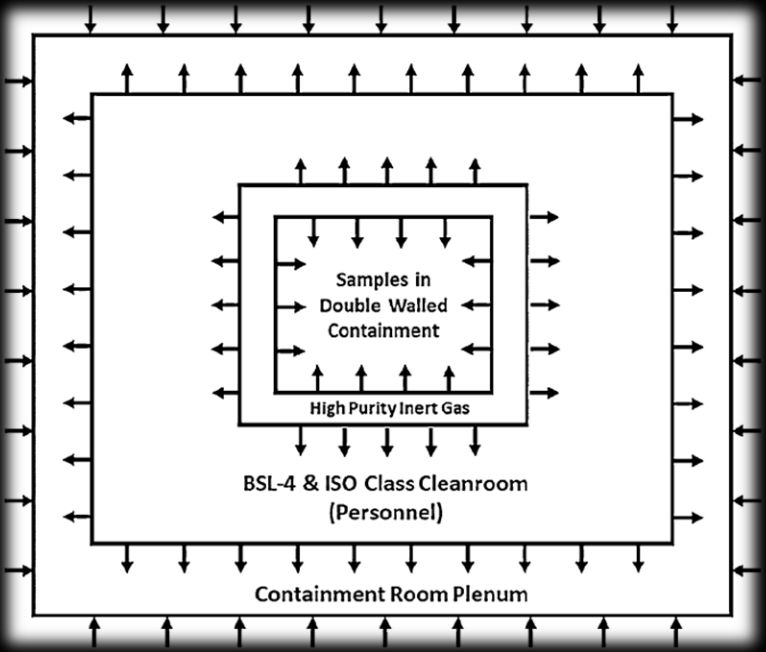
This combined effort requires the integration of both negative and positive pressure environments to meet the needs of PP and contamination control (CC).

Pristine Cleanroom Facilities within High-Containment



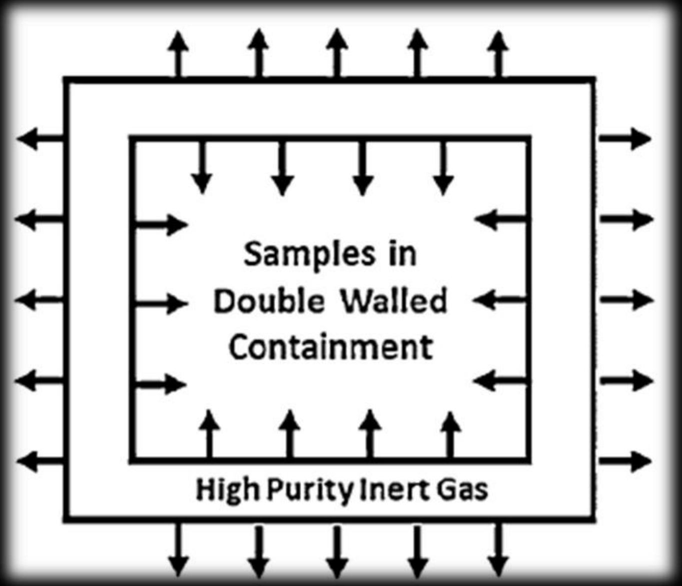
Outermost layer is negative pressure/containment to offer the greatest protection.

Combined facility and specialized isolator approach



This measure may be necessary to ensure sample pristinity is not lost to sterilization in an off-nominal event.

BSC-III Cabinet within a Pristine Glovebox



Innermost layer is negative pressure/containment to offer the greatest protection.

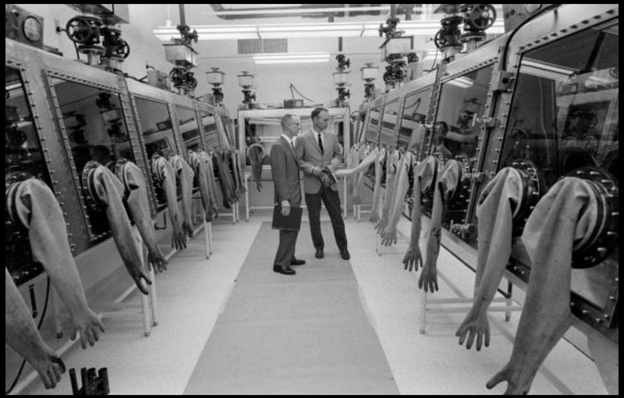
Apollo Lunar Receiving Lab

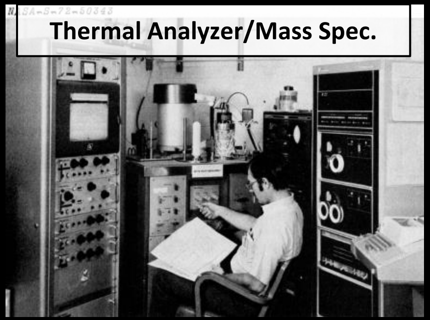
1967 Site Aerial Photo

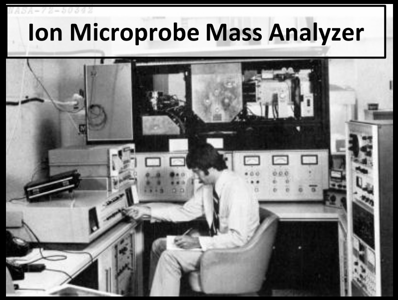
The 84,326 ft^2 (7,834 m^2) LRL facility was designed to the following functional requirements:

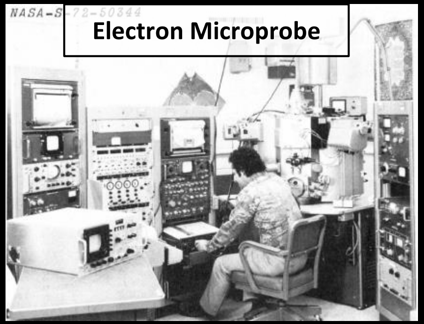
- Prepare sample return containers and astronaut geologic hand tools before flight
- Provide biological quarantine of astronauts, spacecraft, equipment, and samples
- Receive sample return containers and conduct preliminary sample characterization
- Support sample curation: cataloging, sample storage, re-packaging and distribution of lunar samples to the scientific community for analysis
- Perform biohazard clearance testing and time-sensitive primary scientific analyses

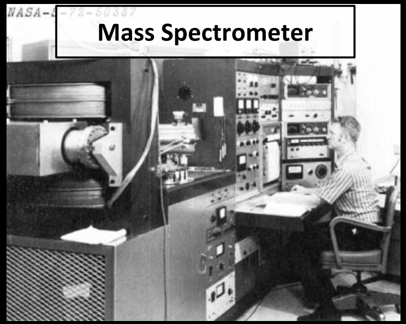
APOLLO LUNAR RECEIVING LAB

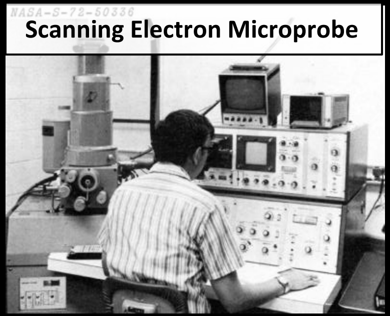


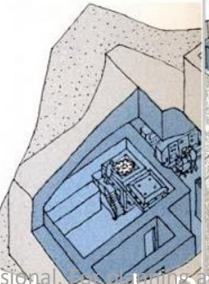


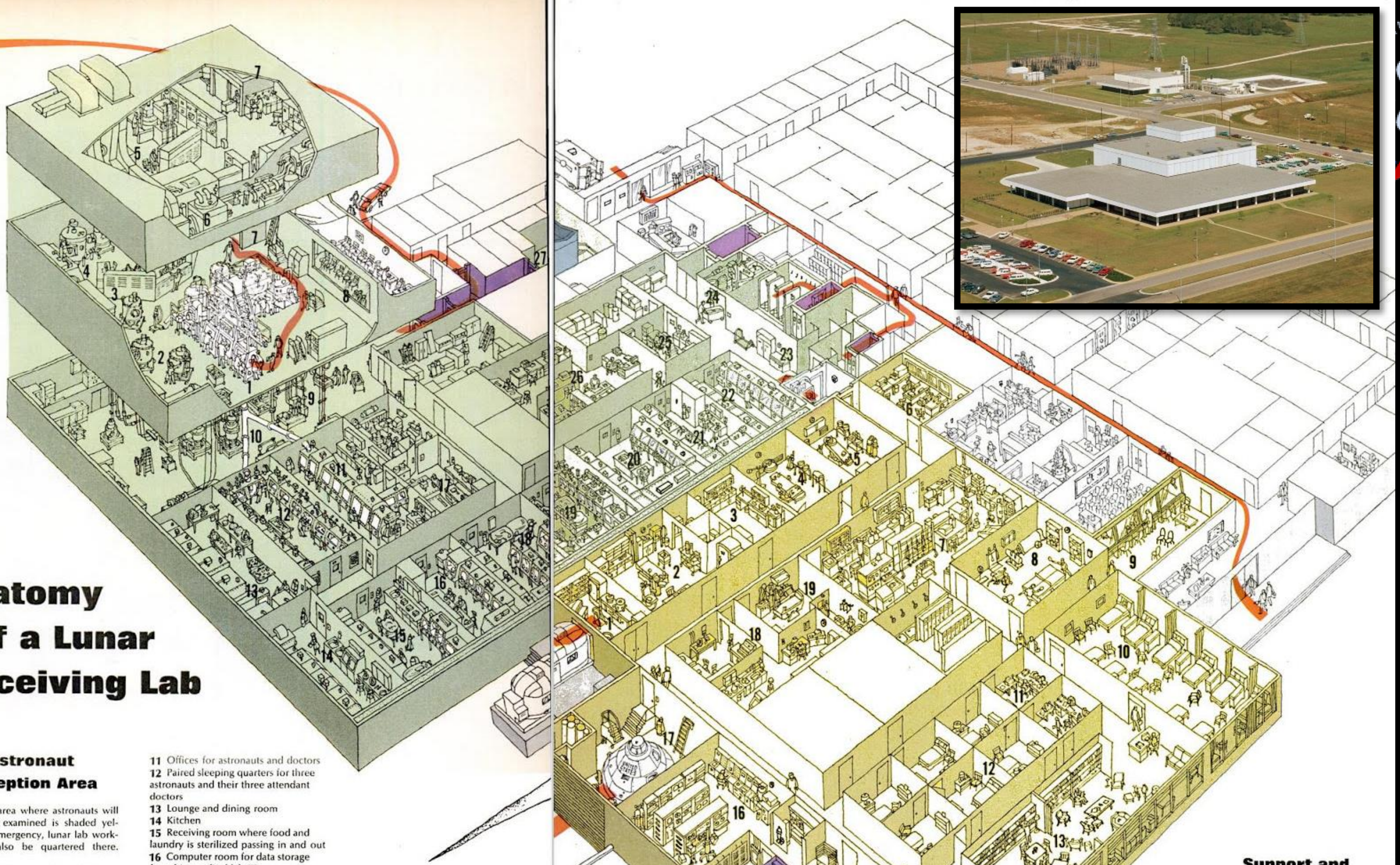












Anatomy of a Lunar Receiving Lab

Routes into biologically isolated sectors of the Lunar Receiving Lab are shown here by red lines. At upper left, lunar samples arrive and are taken to vacuum system and radiation lab by elevator. Other entrances indicated are for astronauts, for the command module, for food and laundry. Lines at far right show where lab personnel come and go through ultraviolet airlocks (purple).

Lunar Sample Laboratory

More than 100 scientists and technicians will perform tests with lunar materials in the lab area, shaded green.

1 Vacuum system where lunar material is received and processed
2 Carousels for storage and transfer of lunar material
3 Controls for vacuum system
4 Equipment for preflight tool sterilization
5 Gas analysis laboratory
6 Special air conditioning system to sterilize air entering and leaving building
7 Elevator
8 Viewing room for participating scientists
9 Pump room and electrical support equipment for vacuum system
10 Transfer tubes for moving samples directly from vacuum system to labs
11 Physical-chemical test lab —mineralogy, petrology, geochemistry
12 Bio-preparation lab where lunar material is prepared, weighed and packaged for distribution
13 Bio-analysis lab for blood tests and other tests on mice
14 Holding lab for germ-free mice
15 Holding lab for conventional mice
16 Lunar microbiology lab to isolate, identify and possibly grow lunar micro-organisms
17 Spectrographic lab and darkroom (connects to 11)
18 Bird, fish and invertebrate lab where shrimp, quail, cockroaches, oysters and other creatures are exposed to lunar material
19 Microbiology lab for test cultures of lunar and astronaut material
20 Egg and tissue culture lab (support and additional facilities for 21)
21 Crew virology lab for postflight virological analysis of astronauts
22 Plant lab where germ-free algae, spores, seeds and seedlings will be exposed to lunar material
23 Entrance to lunar sample operations area. Showers and facilities for all personnel passing in and out to change clothing
24 Autoclave for sterilizing all material entering or leaving area
25 Bio-safety lab to monitor all systems
26 Support offices
27 Entrance to radiation counting lab

Astronaut Reception Area

Quarantine area where astronauts will live and be examined is shaded yellow. In an emergency, lunar lab workers could also be quartered there.

1 Crew reception area (connected to transfer van)
2 Medical and dental examination room
3 Medical examination room
4 Operating room
5 Tilt-table room for physiological testing
6 Tape-out room where data can be passed into nonquarantine area electronically
7 Biomedical lab—clinical chemistries and immunology of astronauts and support personnel
8 Exercise room
9 Astronaut debriefing room, separated by glass from family visiting room
10 Dormitory for support personnel
11 Offices for astronauts and doctors
12 Paired sleeping quarters for three astronauts and their three attendant doctors
13 Lounge and dining room
14 Kitchen
15 Receiving room where food and laundry is sterilized passing in and out
16 Computer room for data storage from bio-medical lab (7)
17 Spacecraft storage, equipped with closed-circuit TV for inspection
18 Microbiology lab for clinical tests of quarantined personnel
19 X-ray room with fluoroscope and darkroom

Radiation Laboratory

Chips from the first lunar samples will be sent to a radiation lab (blue in drawing) built 50 feet underground. There, their radioactivity will be measured and results may help indicate the age of the rocks and whether they ever existed in molten form.

Support and Administration

Beyond the two biologically secure portions of the lab, offices and support facilities are shown at left above. In the light green area, test animals and plants are raised and readied for studies. When quarantine is lifted, other areas in the section will be used to prepare lunar samples for shipment to universities around the world.

Life Magazine
July 4, 1969

Mars Sample Receiving Facility (SRF) Modality Options

- Decommissioned Existing BSL-4 facilities ONLY
- New Traditional, Fixed High-Containment Facility
- New Modular High-Containment Facility
- Hybrid (New + Existing facilities)

DECOMMISSIONED EXISTING BSL-4 FACILITY APPROACH

Assumed Benefits

- Leveraging existing infrastructure
- Built-in high-containment expertise
- Existing community buy-in
- Possible cost and schedule savings

Considerations

- Possible **capacity issues** providing enough lab space
- Accepting **large equipment** (e.g., EEV, DWIs, analytical instrumentation, etc.)
- **Possible cross-contamination vectors** and difficulties keeping an MSR lab clean; complications integrating cleanroom technology
- **Limits on modifications to facility** structure for tailored SRF needs
- Assuring **adequate isolation** from other labs so that unsterilized samples could be safely released (pending sample safety assessment)
- **Programmatic risks** with sharing a facility (competing interest)

New Brick-and-Mortar Facility Approach

Assumed Benefits

- Tailored to SRP's needs
- Method used by all U.S. BSL-4 laboratories constructed to date

Considerations

- Could be the most expensive modality
- Take the longest to implement
- Significant programmatic risk of delay

Contemporary Modular Facility Approach

Assumed Benefits

- Relatively lower costs
- Shorter design/construction/commissioning schedule
- Flexibility for easier retrofits and future expansion
- Tailored to SRP's needs

Considerations

- Modular BSL-4 has never been done before. While this approach has only been used for BSL-3/3Ag facilities, minor modifications should make BSL-4 possible.

The modular elements could be installed in a traditional building (existing or new) or shell structure.

HYBRID CONSTRUCTION APPROACHES

Utilize a combination of the three main modality options (e.g., Annex (Modular and/or Brick-and-Mortar) AND Decommissioned Existing BSL-4 Facilities)

Assumed Benefits

- Shorter design/construction/commissioning schedule
- Flexibility for easier retrofits and future expansion
- Tailored to SRP's needs
- Leveraging decommissioned existing infrastructure
- Built-in high-containment expertise
- Existing community buy-in
- Relatively lower costs and shorter schedule

Considerations

- **Modular BSL-4 has never been done before.** While this approach has only been used for BSL-3/3Ag facilities, minor modifications should make BSL-4 possible.
- Multiple simultaneous construction projects

The advantage of a hybrid approach is that the facility could leverage the strengths of each other's approaches

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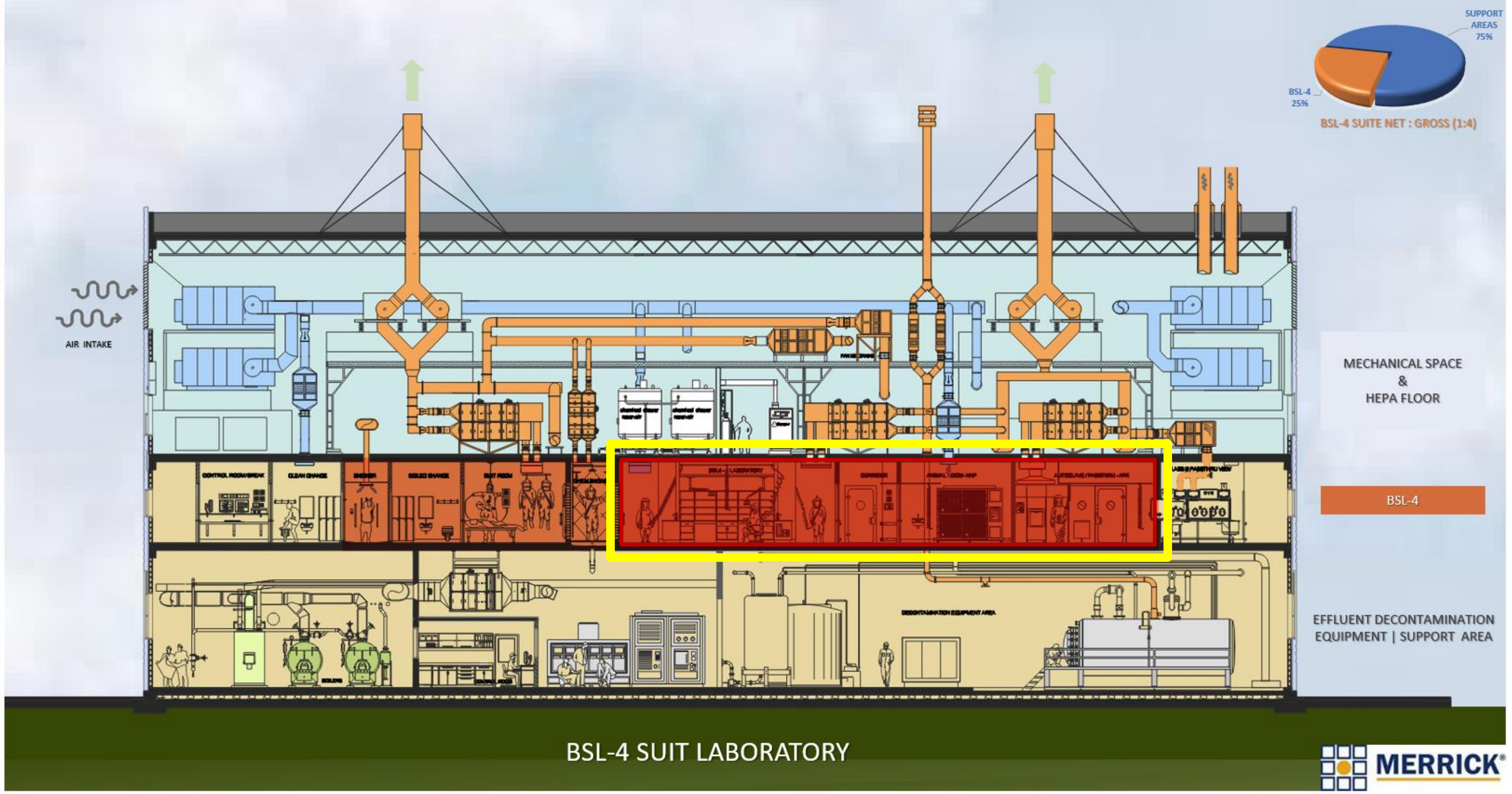
Contemporary Modular Facility in Conjunction with a Decommissioned Existing BSL-4 space

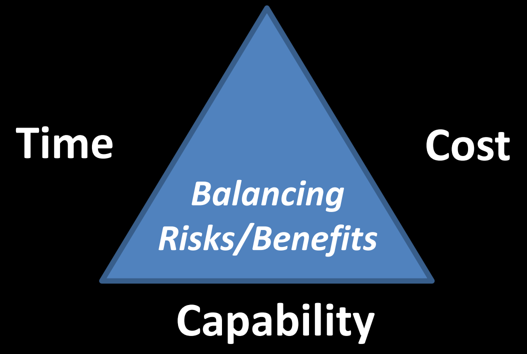
Typical BSL-4 Suite Laboratory Section



Highlight of Overarching Considerations

Mars Sample Receiving Facility (SRF) Assessment Study (MSAS) –
Assess the utilization of 4 modality options and accommodation potentialities

Structural Constraints
Personnel Safety
PP Requirements
CC Requirements
Preliminary Examination Requirements
Science Requirements
Construction Timeline
Operational Timeline
Adaptability to Changing Needs
Facility Fair Use/Access to Samples
Partnership/Reutilization Opportunities
Cost Effectiveness (short and long-term)
Pristine Sample Conservation



Upon completion of the assessment studies, the preferred modality and refined requirements would be utilized for site-specific design but will not be finalized until NASA's completion of the National Environmental Policy Act (NEPA) process.

SRF Notional Instrument List

MSR SRF Instruments	SSAF	Curation & PE	Time Sen. Science	Ster. Sen. Science
Magnetometer		X		
Magnetic Susceptometer		X		
Micro-X-ray diffractometer with total scattering and pair-distribution function (PDF) analysis capability		X	X	X
Petrographic Microscope		X		X
Multispectral/Hyperspectral Imager [10-20 micron resolution]	X	X		
Variable Pressure-Field Emission Scanning Electron Microscope with electron and Focused Ion Beam (FIB) columns and multiple detectors	X	X	X	X
High Resolution X-ray Computed Tomography (HR-XCT)	X	X		
Variable Pressure-Field Emission Scanning Electron Microscope with electron columns and multiple detectors	X	X	X	X
Deep Ultraviolet Fluorescence	X	X	X	X
Confocal Raman Spectrometer	X	X	X	X
Fourier Transform-Infrared Spectrometer (FTIR)	X	X	X	X
Ultra-High Performance Liquid Chromatography Liquid Chromatography (UHPLC-MS/MS) with tandem Mass Spectrometry	X		X	X
Capillary Electrophoresis–Mass Spectrometry (CE-MS)	X		X	X
Electrospray ionization (ESI)-Mass Spectrometry AND/OR MALDI-ESI-MS	X		X	X
Matrix-assisted laser desorption/ionization time of flight (MALDI-TOF-MS)	X		X	X
Gas Chromatography (GC) Isotope Ratio Mass Spectrometer with quadrupole mass spec and higher temperature conversion elemental analyzer (TC/EA)	X		X	X
Epifluorescence Microscope	X		X	X
DNA Sequencer and associated '-omics' equipment (see note)	X		X	X
Real-time PCR machine, i.e. a thermal cycler with fluorescence reading capability	X			
Selected Ion Flow Tube Mass Spectrometry (SIFT-MS) or Photon Transfer Reaction-Mass Spectrometry (PTR-MS)	X			X
Electron Paramagnetic Resonance (EPR) Spectroscopy –			X	X
Brunauer-Emmett-Teller (BET) surface area analysis			X	X
Optical laser spectrometer (Sample Analysis at Mars (SAM) instrument)			X	X
Inductively coupled plasma - optical emission spectrometry (ICP-OES)			X	X
Mössbauer Spectroscopy				X

Instrument list from SSAF and MSPG2 Reports (*Astrobiology 2022*)

MSAS Review Team

- Core Team
  - Technical – Andrea Harrington, Michael Calaway, Richard Mattingly, Alvin Smith, Aurore Hutzler, Francois Gaubert, and Andre Llanos
  - CDC SMEs – Samuel Edwin, Melissa Pearce, Matthew Arduino
  - SRP Science SMEs – Dave Beaty, Brandi Carrier, Fiona Thiessen
- MSAS JSC Extended Team
  - ARES – Danny Carrejo
  - Facilities – Heath Ford & Charles Noel
  - NEPA – Janani Vedanth, Vicky Ryan, and Amy Keith
- MSR Science Leads – Michael Meyer, Lindsay Hays, Gerhard Kminek
- PPO – Nick Benardini, Elaine Seasly, Silvio Sinibaldi

SRF High-Level Notional Schedule & Status

FISCAL YEAR	23	24	25	26	27	28	29	30	31	32	33	34	35	COMMENTS
Sample Receiving Facility														
SRP Formulation														
MSAS Phase 1	SRF Scoping and Modality Down-Selection													
MSAS Phase 2	SRF High-Level Conceptual Designs													
Finalize Major Requirements		Infrastructural Drivers and Operational Scenarios												
Site-Specific Design			Design											
Construction					Construction									
Commission									Final					
Outfit/Test/Training									Install/Test Equipment and Training					
Operations												Fully Operational		
SRF Required Inputs														
Establish Infrastructural Requirements	Curation, science & contamination control (e.g., isolators, cleanrooms, science Instrumentation)													
Planetary Protection & Regulatory	Facility containment, ample isolation & sample safety assessment requirements													
NEPA Inputs/EIS	Tier II: SRF EIS													
R&D - Major Infrastructural Impacts	Infrastructural requirements needed for major equipment (e.g, isolators, large equipment)													
MSR Campaign Science Group(s)	Define science priorities (Inform facility requirements, science instrumentation, R&D tasks)													
Ground Recovery Activity	Scope of activities at landing site, SRF Integration Requirements													

Inform Site-Specific Design
Major infrastructural impacts

Refine Workflows
Minor infrastructural impacts

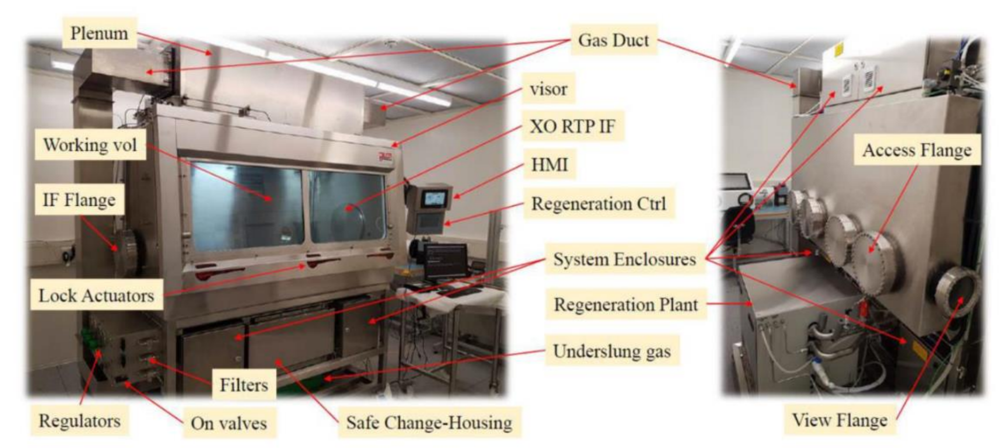
Finalize Instrumentation
No infrastructural changes possible without schedule slip (programmatic risk)

On Schedule

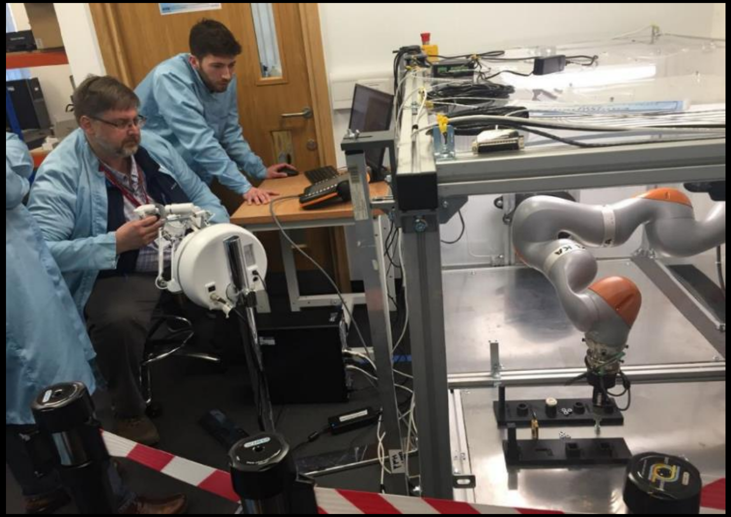
- A&E Firms have provided final inputs for MSAS
- Preliminary Findings are under Stakeholder Review
- Released an RFI to gauge interest in the potential co-development of a new facility https://sam.gov/opp/45ac7570b2cb4c25b926bc7b858111fb/view
- Preparing for MSAS Phase 2
- Working closely with:
  - ESA on all SRF planning activities
  - International MSR Science Working Groups to develop SRF notional requirements

Research & Development in Support of SRF Design & Ops

- Double Walled Isolator (DWI) Design
- Sample handling - Robotic and/or Remote Manipulation
- Sample Tube and Subsample Isolation Containers for Analyses Outside SRF
- High-Containment suit and infrastructural material contamination control testing
- Quantify contamination loads of existing BSL-4 facilities
- Instrument accommodations
- Sample sterilization
- Infrastructural cleaning and sterilization procedures



DWI Breadboard at U. Leicester



Robotic Manipulation Breadboard at Thales Alenia UK

Close collaboration between NASA/ESA's Curation, Science, and PP Teams

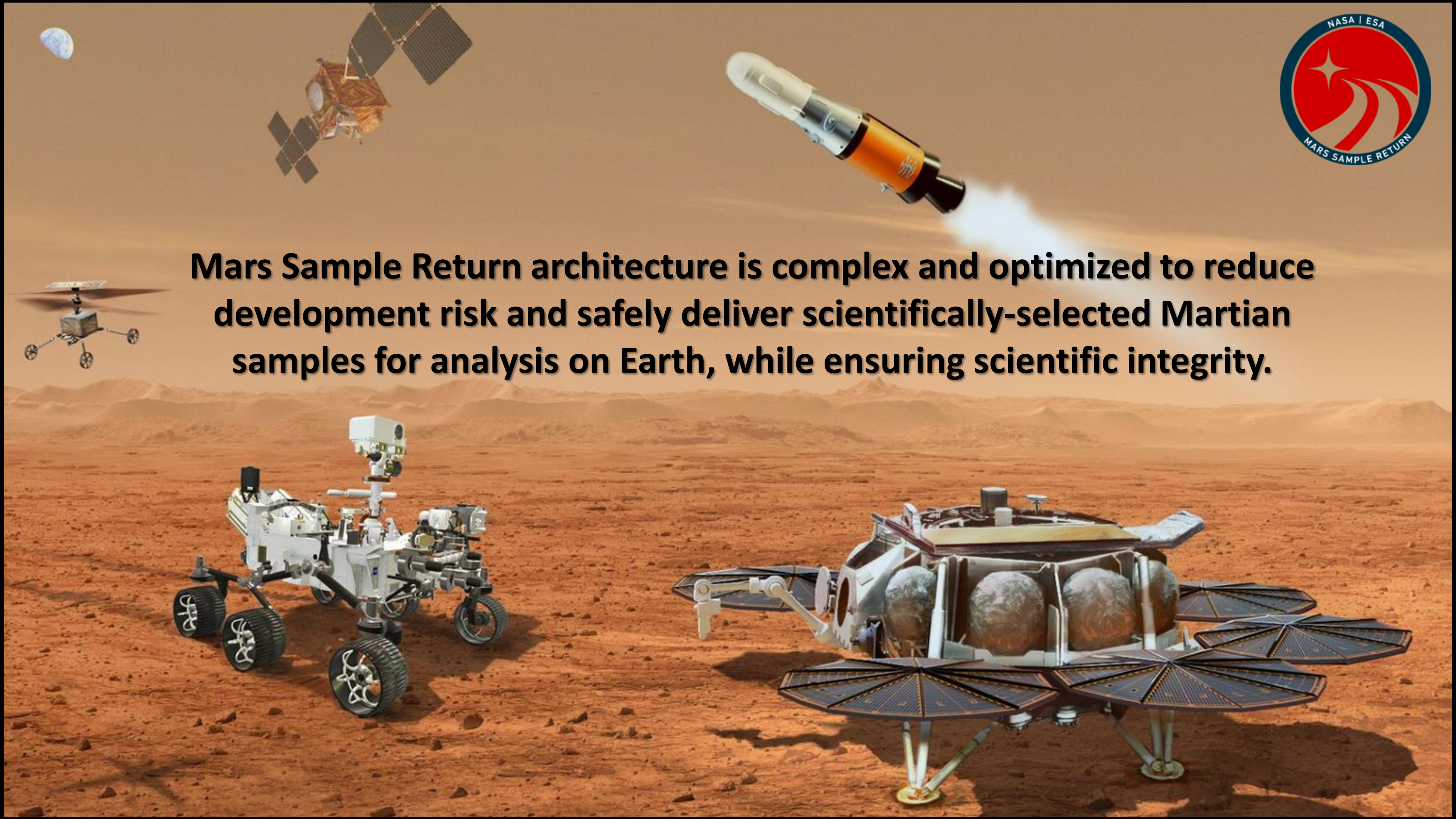
Closing Highlights

- Proper prioritization of the considerations will enable a highly capable, fully operational SRF by October 2033.

- NASA and ESA are taking a "safety first" approach to designing and engineering every step of Sample Receiving Project (SRP).
  - Complementary NASA/ESA SRF studies will inform site-specific design.
  - Conducting R&D activities (e.g. DWI) to comply with Planetary Protection and Contamination Control objectives.

- The nature of SRP planning requires effective communication across Agencies (national and international), Centers, the scientific community, and the general public.

QUESTIONS?


Mars Sample Return architecture is complex and optimized to reduce development risk and safely deliver scientifically-selected Martian samples for analysis on Earth, while ensuring scientific integrity.